The commissioning of the ATLAS calorimeters with cosmic muons

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THE COMMISSIONING OF THE ATLAS CALORIMETERS WITH COSMIC MUONS

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The commissioning of the ATLAS calorimeters is an ongoing process since early 2006. During this period, cosmic muons have been recorded in several runs combining both hadronic and electromagnetic calorimeters. Among the goals are the measuremement of the uniformity of the liquid argon electromagnetic calorimeter to the level of 1% and the intercalibration in time of its channels to 1 ns.

1 Commissioning with cosmics

The ATLAS EM calorimeters undergo in 2007 the last steps of their installation. During the previous two years of commissioning, several milestones have been successfully attained, most prominently the complete cabling of the whole electronics chain, the cryostats fill with liquid argon and the high voltage ramping. The calorimeters in this definitive setup could then detect the cosmic muons reaching them in spite of their location 150 m underground in the cavern.

1.1 ATLAS calorimetry during the commissioning

The commissioning involves all calorimeter subdetectors for which a detailed description can be found in the ATLAS Technical Design Report [1]. The endcap regions being operational only since a few months, the emphasis will be put on the barrel part from which more information can be extracted with this special data taking. The trigger signal is provided by the hadronic calorimeter detecting top-bottom coincidences at a rate of one event every 20 seconds. Monte-carlo simulations had predicted a strong occurence of incoming muons making their way down the access shafts. The accumulated data corroborate this idea with a maximum of events originating

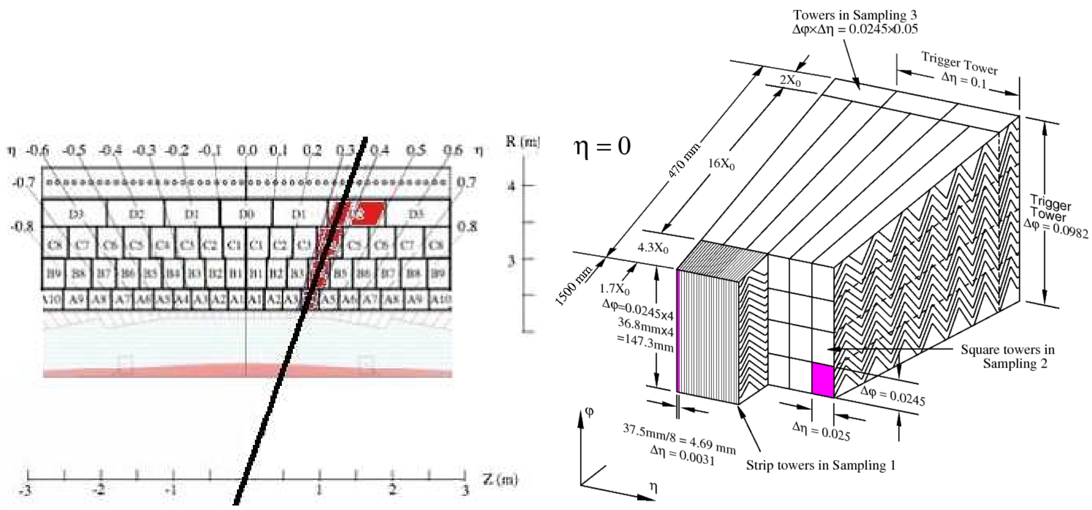

Figure 1: The η coverage made available by the tile calorimeter (left) and a schematic view showing the accordion geometry of the LAr EM calorimeter (right).

from that direction at $|\eta| \sim 0.3$. The coverage of the trigger ranges basically up to $|\eta| < 0.8$ as seen in fig.1, the rates falling abruptly beyond this rapidity.

The liquid argon technology used as active material of the electromagnetic calorimeter was adopted for its high stability and radiation hardness. This sensitive part is located in the gaps between the absorbers, accordion shaped plates made of lead. The schema of fig.1 shows the longitudinal segmentation of this detector in a front, middle and back compartments. Due to its larger depth, the middle layer collects most of the small signals left by muons and will hence be subject to a more detailed analysis.

1.2 Motivations

Since the ATLAS Collaboration unveiled the first data taking of cosmic muons in August 2006 (fig.2), an effort has been initiated in order to improve the knowledge of the calorimeters. Though the preceding testbeam data have brought much to our understanding, it is an opportunity to assess the behaviour of still untested modules.

Muons propagating almost at the minimum of ionisation do not offer optimal conditions for measuring performances of the EM calorimeter. The small energy deposits they produce amount typically to 275 MeV in the middle, only a factor 8 above the electronic noise and two orders of magnitude below the energy scale relevant to the LHC physics. Unlike the LHC environment, cosmic muons produce asynchronous data and their trajectories are seldomly projective, i.e. passing close to the interaction point. On the other hand, muons have well-understood energy deposition mechanisms and, unaffected by non-uniformities in the absorbers, they give a direct sensitivity to the width of the liquid argon gaps and effects due to a wrong calibration or signal reconstruction. They also allow to scan a large fraction of the detector without concerns about the energy of the incoming particles. A simulation of projective muons has demonstrated that a precision of 1% on the value of the most probable energy deposit could be achieved for each η range of the middle with the statistics accumulated during 3 months.

Another motivation comes from the observation of large energy deposits in the calorimeter interpreted as muons emitting a photon which then produces an electromagnetic shower. In the figure 2, an example of a high amplitude signal is shown, representing an equivalent of 25 GeV. These events can be exploited in various ways, for instance to validate predictions of the physics pulse shapes or to be used as reference when intercalibrating in time the channels. From the

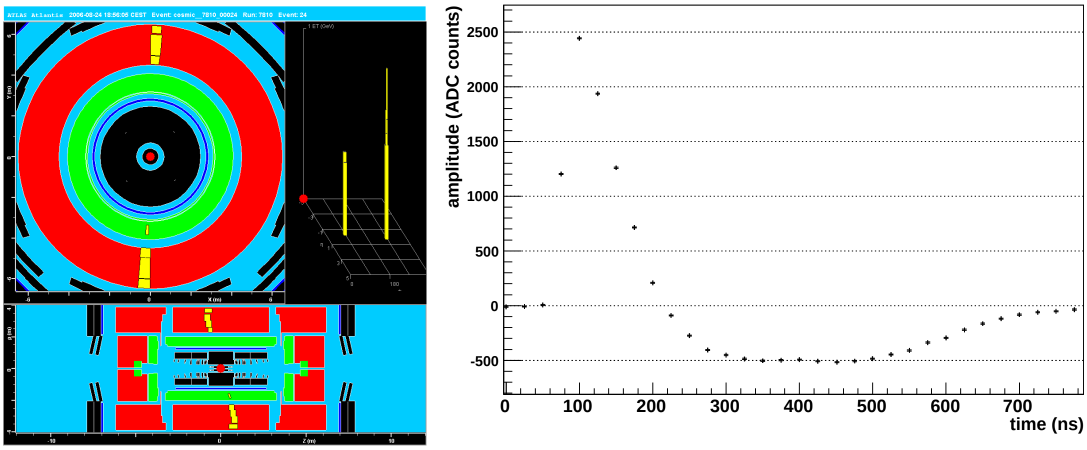

Figure 2: On the left, an event display from August 2006 cosmic data shows the energy deposits left by a projective muon in the hadronic (red) and electromagnetic (green) calorimeters. Large signals of several GeV like the one appearing on the right hand side are frequently encountered.

current observed rate, we can expect at least one such event per cell after the planned data taking period (3 months). Reversely, the absence of signals identifies dead channels. An amount of 60k muon signals have been recorded during the 3 days long runs taken in fall 2006 with a limited coverage and a high voltage set to 1600V. In the first half of 2007, more regular runs were taken overnight and during weekends with a more complete setup.

2 Results

The challenges related to the analysis of cosmic muons had to be overcome. For instance, the optimal filtering method[2] used for the signal reconstruction in the EM calorimeter does require the knowledge of the pulse's time. Though it can be evaluated *in situ* with large signals, this information will be provided by the hadronic calorimeter. Another issue concerns the signal to noise ratio which should be improved as much as possible. The low event rate allows data taking with more samples than the nominal 5 at the LHC. A significant reduction of the noise is obtained when performing instead an optimal filtering with 29 samples (see fig.3). Is also shown the Landau distribution of the deposited energy of the muons.

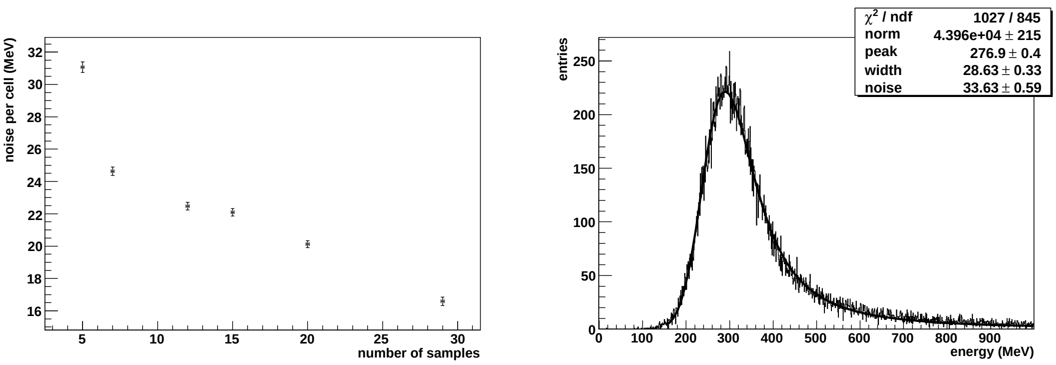

Figure 3: The noise is reduced by a factor 1.8 if the number of samples for the optimal filtering is increased from 5 to 29 (left). The graph on the right is the Landau distribution of muon signals observed during the testbeam. The electronic noise is taken into account by a convolution with a gaussian.

2.1 *Uniformity in energy*

Due to the accordion geometry, a signal is always shared between two neighbouring cells in ϕ. Adding these two cells would contain the whole signal as long as the muon is projective enough to not leak in adjacent cells in η for instance. Criteria to assess the biases introduced by the non-projectivity are under study. At this point, signals in the front could be used to determine more precisely the paths and hence avoid this issue. Out of the accumulated data, around 5% are described as projective enough to be considered in a uniformity measurement. Though each muon produces signals at the top and bottom of the calorimeter, the limited statistics of projective muons allows to seek for effects along η (fig.4) only with the assumption of symmetries of the detector in ϕ, top versus bottom and between A or C sides.

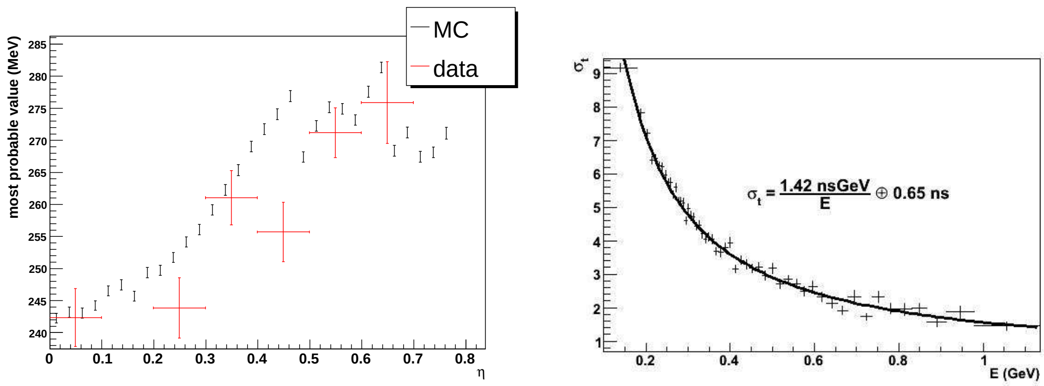

Figure 4: On the left, this preliminary graph shows a comparison between data and MC of the peak of the Landau shape for various η ranges. The time resolution for muons as a function of the energy is presented on the right.

2.2 *Intercalibration in time*

To perform an intercalibration in time of two channels, a single particle crossing both of them would be sufficient after a correction for the time-of-flight. Unfortunately, the time measurement remains very unprecise at low amplitudes (see fig.4). Large signals allow to measure precisely the relative offsets between the tile and electromagnetic signals. With more data being analysed, these reference signals will help to disentangle the various sources of offsets and solve the system such that all the channels are intercalibrated to 1 *ns*.

3 Conclusion

With more components becoming operational in ATLAS, recent cosmic runs taken in Spring 2007 are already integrating parts of the inner detector (TRT) and the muon system. Uniformity analysis and time intercalibration are currently performed in order to understand as much as possible the calorimeters before the LHC start-up next year.

References

1. Atlas: Detector and physics performance technical design report. volume 1. CERN-LHCC-99-14.
2. O. Benary et al. Precision timing with liquid ionization calorimeters. *Nucl. Instrum. Meth.*, A332:78–84, 1993.